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Observations on the fast ice biota in the fjords of Spitsbergen

ABSTRACT: Chlorophyll *a*, phytoplankton, suspensions and zooplankton beneath the fast ice have been studied in Spitsbergen fjords (Hornsund, Bellsund, Sassenfjord, Gronfjord and Kongsfjord) in 1982, 1984/85, 1987 and 1988. Observations on ice associated Polar cod and wildlife have been collected simultaneously. There were no typical sympagic communities observed at the West Spitsbergen fast ice. Exception was spring 1982 and 1988 when drifting ice from Barents Sea contributed to the fjords fauna. Fast ice on the investigated fjords was poor in adjacent zooplankton (biomass below 0.06 g/m^3). Ice phytoplankton reflects the autumn situation and no specific communities of algae have been found. Chlorophyll *a* amount and organic sedimentation from ice and from the adjacent water were very similar (0.4 to 1.7 mg/m^3 chlorophyll and 8 to 10 g d.w./m^2/day sedimenting matter). The diet of Polar cod reflected the food items occurrence, *Calanus* has been the most common food. No specific concentration of seabirds have been observed at fjords ice.

K e y w o r d s: Arctic, Spistbergen, ice biota, fjords.

Introduction

Sea ice biology was the object of extensive studies during past decade in the European Arctic, especially after MIZEX, FRAM, PRO MARE and Greenland Sea projects (Newbury 1983, Gulliksen 1984, Smith et al. 1985, Saksaug 1986, Saksaug and Skjoldal 1989). The cryopelagic (ice) biocenose is relatively well known in Central Arctic, after studies by Barnard (1955) and Melnikov (1989). Ice biota from inland bays and coastal areas of the Arctic have been studied among others by Golikov and Scarlato (1973), Golikov and Averincev (1977), Green and Steele (1977), Carey and Montagna (1982), Bradstreet and Cross (1982), Cross (1982), Grainger, Mohammed and Lowry (1985). Major reviews on ice biota have been prepared by Horner (1976, 1985), Horner et al. (1989) and Melnikov (1989). Spitsbergen fjords have not been studied with regard to the fast ice ecology. The exception was sampling by r/v "Polarstern" in Van Mijenfjorden in 1985 (Diel 1991), and study on fast ice as breeding habitat for the ringed seals (Smith and Lydersen 1992). The aim of the present study is to support physical observations on the fast ice published by Görlich and Stepko (1992) with ecological data and to present ecological importance of the fast ice in fjords ecosystem.

Material and methods

Observations on the fast ice biota have been collected from Polish Polar Station in Hornsund in 1978/79, 1981/82, 1982/83, 1984/85, 1986/87, 1987/88. Observations have been collected by the authors and other members of Polish wintering expeditions. In spring 1985, 1987 and 1988 sampling was conducted in other Spitsbergen fjords (Fig. 1). For chemical and biological analyses lower 20 cm of ice cores of 10 cm diameter have been cut and melted in laboratory in 10°C. For chlorophyll analyses water was filtered through GF/C filters and

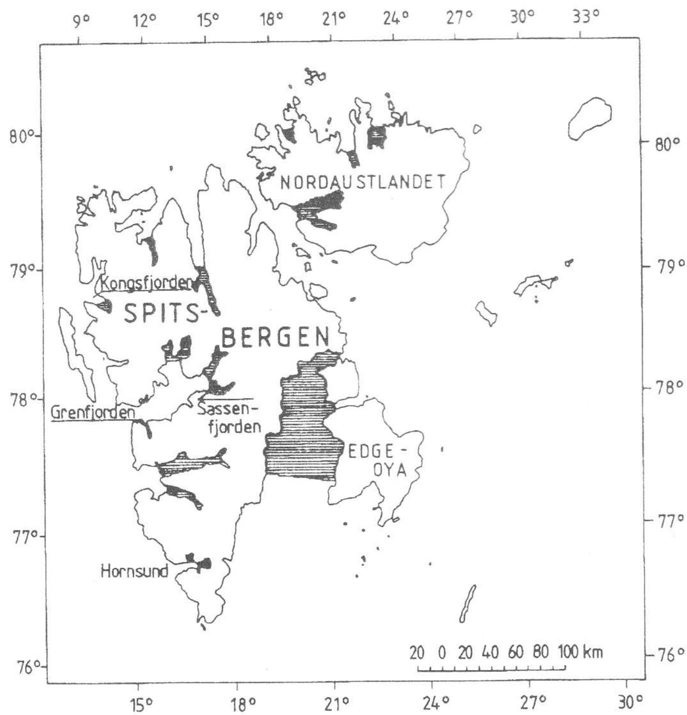

Fig. 1. Svalbard archipelago with investigated fjords. Fast ice cover shaded.

analysed according to Strickland and Parsons (1972) recommendations. One liter of melted water was filtered on 0.45 Milipore filters in order to obtain suspensions concentration. Filters were dried in 60°C for 48 hours, weighed, later burned in 450°C and weighed again to obtain the mineral part in suspensions weight.

Sedimentation from ice has been measured with the use of set of five plastic cylinders of 2.8 cm^2 diameter each, held in metal container, tightly attached to the even undersurface of ice. Such sediment trap for particles falling from water surface was placed at 1 m depth under the big opening in the ice. Zooplankton samples were collected with WP-2 net of 0.25 m^2 opening diameter and 200 μm mesh size, hauled from 10 to 0 m depth. Samples were preserved in 4% formaldehyde solution buffered in sea water. Biomass was measured after weighing wet formaline weight with 0.1 mg accuracy and estimating the displacement volume of sample. Biomass of particular species was also calculated from formulas on length/weight relationship given by Matishov (1991). Ice fauna was collected also with hand nets, scraping undersurface of ice; that was the way to cath Polar cod and large motile crustaceans. Terms used in this study are given as in World Meteorological organisation's ice terminology (Michalczewski 1981), where fast ice is the cover growing seaward from the coast and reacting on the sea level changes. As sympagic fauna the authors understand organisms associated with the sea ice in the sense used by Gulliksen and Lonne (1989) elsewhere described as cryofauna (Golikov and Averincev 1977). Fast ice cover lasts from 3 to 9 months per year in the fjords of Spitsbergen Island depending on the year and fjords configuration. Fjords freeze usually in December, ice cover consolidates in January and lasts until late May. Fast ice reaches 1.6 m thickness at maximum, on average less than 1 m. (Węsławski and Adamski 1987, Görlich and Stepko 1992, Smith and Lydersen 1992).

Results

Suspensions and sedimentation. In the course of the winter the amount of sediment in fast ice from Hornsund varied between 3.5 and 15 mg dry weight per dm^3 (Tab. I). Vertical cross section shows nearly even distribution of mineral sediment in fast ice core, except higher concentration in the surface snow layer (Tab. II). The organic suspensions were distributed in ice differently. Nearly absent in the upper parts of the core and concentrated in the lowest, bottom part of the ice (Tab. II). The amount of organic matter sedimenting from the ice reached 8 g d.w. per day per m^2, compared to 6 g sedimenting from the adjacent water in spring. In Sassenfjorden the relation between ice and surface water sedimentation was similar in two years of our survey (1987 and 1988) although the total amount of sedimenting matter differed significantly (Fig. 2).

Table I

Characteristics of near shore fast ice cover at Hornsund, 1984/85, mean values from 3 samples each month

Month	Salinity []	Sediment [mg/dm³]	% of organic matter	Chlorophyll a [mg/m³]	SiO_2 [µmg/dm³]	PO_4 [µmg/dm³]
December	8.4	4.0	0	0.04	5.63	0.83
January	11.0	9.9	42	0.02	1.38	0.29
February	15.0	15.5	62	0.25	1.61	0.51
March	14.0	6.3	45	0.18	2.13	0.13
April	4.0	3.5	36	1.96	0.88	0.13
May	4.0	7.3	39	0.85	no data	no data

Table II

Vertical cross-section of fast ice in Hornsund, April 1985

layer [cm]	salinity []	mineral sediment [mg/dm³]	organic sediment [mg/dm³]	chlorophyll [µmg/dm³]	temperature [°C]
snow	?	10	0	?	−14.5
0−40	1.14	4	1	?	−7.0
40−90	4.13	4	1	?	−2.1
90−120	2.84	5	25	1.74	water −1.88
water	4.6−33.6	0	25	0.4−4.16	−1.88

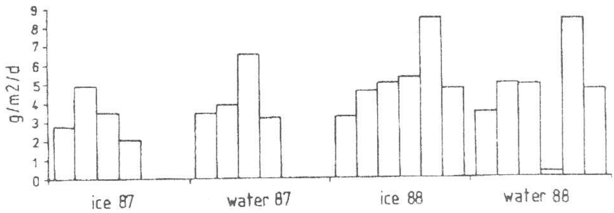

Fig. 2. Amount of sedimenting matter from fast ice and open water in Sassenfjorden, May 1987 and 1988, data in three days intervals, in g dry weight per m² per day.

Chlorophyll *a*, **nutrients, net phytoplankton**. The bottom part of the fast ice cores from Hornsund contained 0.02 to 0.18 mg per dm³ before the bloom and nearly 2 mg chlorophyll *a* per dm³ during the bloom in late April (Tab. I). Similarly in Sassenfjorden the chlorophyll *a* amount in ice during the bloom ranged from 1.0 to 1.74 mg chlorophyll *a* per dm³ (Tab. II). After the bloom, water patches on snow and ice contained high concentration of chlorophyll *a*, up to 20 mg per dm³. Silicates concentrations in fast ice core ranged between 1.38 and 5.63 µmgat with characteristic drop to 0.88 µmgat during the diatoms bloom (Tab. I). The amount of phytoplankton in ice samples reached maximum at 13 × 10^8 cells per m³ in two samples examined from Sassenfjorden in 1987. In analysed net phytoplankton samples 38 taxa have been found, 9 only in ice, 14 only in

Table III

Frequency of occurrence of phytoplankton taxa in ice (8) and water (10) samples, Sassenfjorden, May 1987

Taxon	F % ice	F % water
Amphiprora hyperborea	33	0
Dinophysis rotundata	17	0
Protoperidinium brave	17	0
Biddulphia aurita	17	0
Stauroneis sp.	17	0
Nitzschia frigida	17	0
Nitzschia sp.	17	0
resting spores	17	0
Nitzschia delicatissima	17	0
Protoperidinium minutum	0	40
Gymnodinium sp.	0	40
Chaetoceros socialis	0	40
Protoperidinium cf. *subcurvipes*	0	20
Protoperidinium curvipes	0	20
Protoperidinium islandicum	0	20
Chaetoceros affinis	0	20
Chaetoceros constrictus	0	20
Chaetoceros brevis	0	20
Chaetoceros ceratosporus	0	20
Thalassiosira antarctica	0	20
Thalassiosira nordenskioeldii	0	20
Nitzschia longissima	0	40
Phaeocystis pouchetii	0	20
Thalassiosira gravida	67	60
Protoperidinium divergens	67	60
Protoperidinium spp.	67	40
resting spores	67	60
Nitzschia spp.	33	80
Tintinnoidea	33	60
Thalassiosira baltica	33	60
Nitzschia grunovi	17	60
Licmophora spp.	33	20
Protoperidinium pellucidum	33	60
Navicula sp. „*radiosa*"	17	40
Ceratium arcticum	33	20
Achnanthes taeniata	33	20
Chaetoceros spp.	17	40
Pleurosigma spp.	17	40
Pennatae n. det.	17	20
Fragilaria spp.	17	20
Navicula spp.	17	20
Bacterosira fragilis	17	20

water and 20 both in ice and water samples (Tab. III). Diatoms dominated both in ice and water biota constituting more than 70% of all the taxa found. The most common were pennatae diatoms (*Thalassiosira gravida*) and two phaeophytes from the genus *Protoperidinium* (Tab. III).

Zooplankton. Under fast ice zooplankton was represented by 34 taxa collected in 40 samples from four fjords (Tab. IV). The most common were copepodit stage of *Pseudocalanus acuspes, Calanus finmarchicus/glacialis* and cirripedian nauplii. Among macroplanktonic organisms adults of *C. finmarchicus*, larvae of crab *Hyas araneus* and chaetognathes were the most frequent. The biomass of under ice zooplankton was estimated from 0.004 to 0.06 g wet weight per dm^3 (calculations from the length/weight formulas) or 0.02 to 0.07 g w.w./dm^3 after direct weighing (Tab. IV). The highest biomass values were found in Kongsfjorden in spring 1988 where large *Gammarus wilkitzkii* specimens occurred. The length frequency of most important plankters found in our samples shows that *G. wilkitzkii* and *Onisimus littoralis* populations consisted of oldest, biggest specimens while *Themisto libellula* of juveniles only. *Sagitta elegans* population was the only one represented by all size/age classes in our under ice samples (Fig. 3). Occurrence of prey items in stomach of Polar cod (*Boreogadus saida*) have been compared with such from the zooplankton samples beneath the ice (Fig. 4). Polar cod 10 to 14 cm in length was feeding pimarily on the most common prey (*Calanus* spp.) with slight preference to Decapoda larvae.

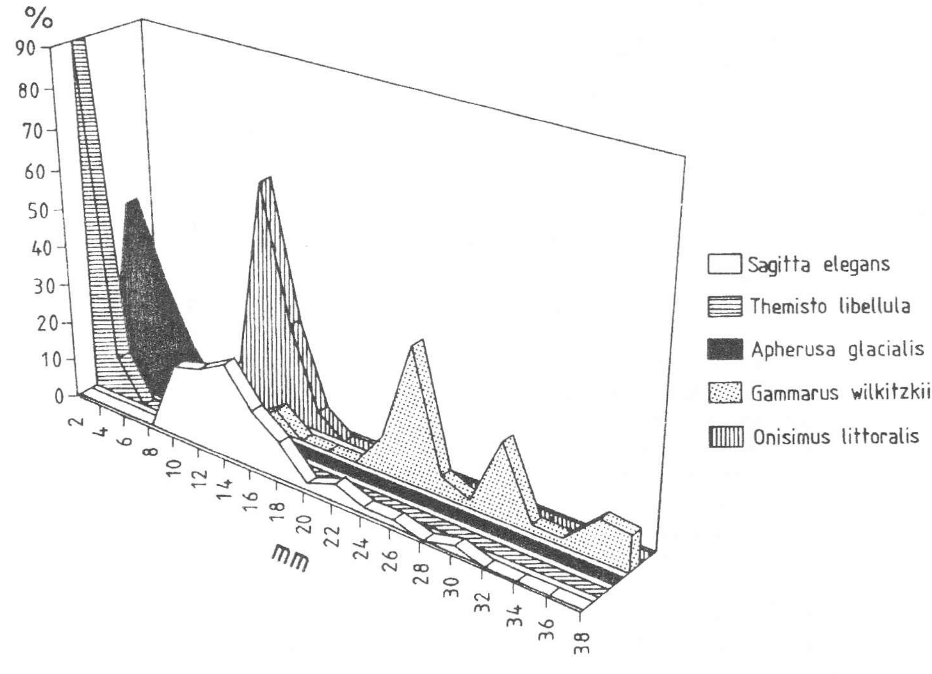

Fig. 3. Length frequency of dominant macroplankton species found under fast ice

Table IV

Mean density of under fast ice zooplankton (individuals per m^3) in Spitsbergen fjords

region samples date	Hornsund n=15 April'85	Gronfjord n=4 May'85	Sassenfjord n=9 May'87	Kongsfjord n=6 May'88
mesozooplankton (0.1 – 5.0 mm)				
Calanus finmarchicus/glacialis, copepodit 1 – 4	5.8	2.0	79.6	12.2
Pseudocalanus acuspes, adults	71.0	5.0	61.2	5.5
P. acuspes, copepodit 1 – 4	206.0	0	31.2	289.5
Microcalanus pygmaeus	0	0	1.6	19.3
Metridia longa	0.33	0	0	0.17
Acartia longiremis	2.0	0	0	5.5
Oithona similis	47.5	8.0	24.0	82.0
O. atlantica	0	0	0	1.3
Oncaea borealis	0	0	0	5.3
Harpacticoida	1.7	1.0	0.6	0
Copepoda, nauplii	36.0	418.0	215.0	3.0
Cirripedia, nauplii	422,0	379.0	337.0	0
Isopoda sp., juveniles	0	0	0	0.13
Polychaeta, larvae	1.7	5.0	3.6	0
Limacina helicina	0.17	0	1.0	0.7
Echinodermata, larvae	0	9.0	0.8	0
macroplankton (over 5 mm)				
Calanus finmarchicus/glacialis, adults	1.2	0.25	5.8	2.3
C. hyperboreus	0	0.17	0	0.17
Aglantha digitale	0.06	0.01	0	0
Hydromedusae, n. det.	0.09	0	0	0
Beroe cucumis	0.053	0	0	0
Clione limacina	0	0	0.09	0.013
Eupagurus, zoea	0.01	0	0	0
Hyas, zoea	0.033	0	0.66	2.31
Martensia, ovum	0.019	0	0.22	0
Onisimus littoralis	0	0	0.044	0.31
Gammarus wilkitzkii	0.007	0	0	0.16
Gammarellus homari	0.006	0	0	0
Thysanoessa inermis	0	0	0	0.013
Themisto libellula	0.018	0	1.6	0
Sagitta elegans	0.1	0	0.27	0
zooplankton calculated biomass [mg wet weight per m^3]	18.49	4.0	49.12	62.5
zooplankton wet weight [mg w.w./m^3]	36.8	17.6	71.8	no data
zooplankton displacement vol. [mm^3]	no data	no data	0.11	no data

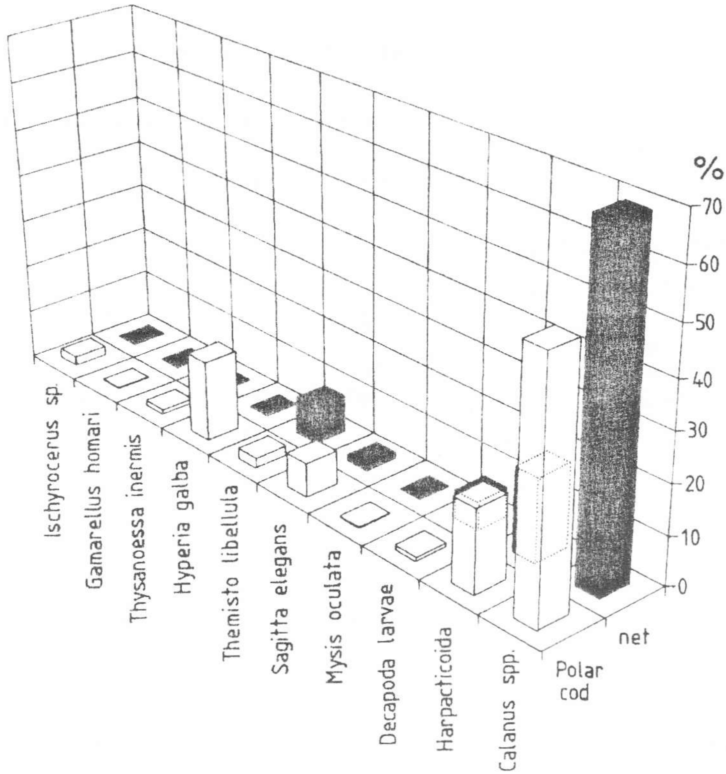

Fig. 4. Occurrence of food items in Polar cod stomachs (18 fishes) and under ice plankton samples (34)

Birds and mammals on the fast ice. Only few birds have been observed during our field work on the West Spitsbergen fjords fast ice. Ivory and Glaucous gulls were seen commonly feeding on seal carcases. In the water channels and polynyas Black guillemots were the most common, occasionally accompanied by Little auks and Kittiwakes. We have never observed any dense seabirds concentrations in the fast ice area. Ringed seal was the most common animal in inner fjord basins, amounting to some hundred individuals in Hornsund and Sassenfjorden. Polar bear was common and frequently observed while hunting in the inner part of Hornsund, while only single specimens were observed in other West Spitsbergen fjords.

Discussion

Fast ice forms observed in West Spitsbergen fjords were of typical character for the Arctic with the exception of multiyear grounded ice absence, commonly reported from the High Arctic (Zubov 1945, Golikov and Averincev 1977). Among investigated fjords, Hornsund represented greatest variety of ice forms due to its openess to the Greenland Sea and frequent inflows of ice pack from

East Svalbard (Vinje 1977, Węsławski and Adamski 1987, Görlich and Stepko 1992). Frequency of breakups in the West Spitsbergen fjords is probably higher than in other Arctic areas. It was mainly due to the direct contact with the warm Atlantic current and oceanic storms from the West blowing straight to the mouths of the fjords (Pereyma 1983). Duration of fast ice cover in the investigated area rarely exceeds 6 months, while 9 months cover is typical of most of the High Arctic (Zubov 1945, Atkinson and Wacasey 1987, Averincev 1989).

Amount of sediment in fast ice from the investigated area is comparable to that in water in the time of freezing (Görlich, Węsławski and Zajączkowski 1987). Some authors indicated the enrichment of fast ice in sediment, by its entrapment by ice cover in coastal areas (Tarasov 1981). The chlorophyll *a* content and amount of phytoplankton in fast ice were low in our samples compared to other reports. In Central Arctic Melnikov (1989) and Okolodkov and Latyshev (in press) have found concentrations ranging from 0.2 to 39 mg/m^3 of ice. There are about 200 species of ice associated algae reported hitherto from the Arctic (Horner 1976, Hsiao 1980, Melnikov 1989). The lack of specific phytoplankton assemblages in fast ice of the Spitsbergen fjords emphasises its seasonal, one year character. Ice algae assemblages found in our spring ice samples have developed from those present in autumn when fjord was freezing. That is similar to the Baltic Sea ice algae reported by Huttinen and Niemi (1986). Prymnesiophycean *Phaeocystis pouchetii* is commonly regarded as the key species in Arctic phytoplankton (Eilertsen, Taasen and Węsławski 1989). We have not found *P. pouchetii* in ice core samples, although it was abundant and relatively common species in the adjacent water body. The algae bloom in ice covered waters is commonly reported to start only after the ice cracking (Sakshaug and Skjoldal 1989). Contrary to these reports we have observed the well developed algae bloom under solid fast ice cover, 10 to 20 km from the nearest ice edge. Fast ice cover after being crushed often remains drifting in the fjord for weeks. Such eroded ice floes bring considerable amount of periphytic and benthic algae well after the spring bloom is gone. This suggest that fast ice may have important role in prolonging the algae bloom in coastal areas. Zooplankton biomass ranged from 0.1 to 10 g w.w. under 1 m^2 under ice pack in Barents Sea (Gulliksen 1984, Lonne and Gulliksen 1989) and 2.5 g/m^2 under the Antarctic fast ice (Forster 1987). Density of the dominant plankters ranged from 20 to 60 individuals per m^3 of *Calanus* spp. under Greenland pack ice (Smith et al. 1985) to 1330 ind./m^3 of *Pseudocalanus elongatus* under fast ice in the Frobisher Bay (Grainger and Hsiao 1982). The results of our observations are within the range of lowest values reported from ice biota.

Gulliksen and Lonne (1989) described ice associated fauna as autochthonous and allochthonous species. In the case of West Spitsbergen fjords autochthonous *G. wilkitzkii* have been observed in the years of pack ice inflows only (Węsławski and Adamski 1987). Such inflow in 1988 explains also the presence of *G. wilkitzkii* in our samples from Kongsfjorden. Gulliksen (1984) indicated scarcity of *G. wilkitzkii* under the one year ice in contrast to the multiyear pack ice. The highest density and biomass of autochthonous ice crustaceans have been noted in grounded multiyear fast ice on Franz Josef Land, up to 36 g/m^2 (Golikov and Averincev 1977). In our hand net ice samples from Hornsund, coastal and benthic amphipods have been commonly found (*Ischyrocerus* spp., *Gammarellus homari* juveniles, *Gammarus setosus* juveniles, *Onisimus littoralis*) similarly to the reports from the Canadian Arctic coastal waters (Cross 1982). The diet of Polar cod under fast ice in Hornsund is highly similar to such observed in the open Svalbard waters and one year sea ice (Lonne and Gulliksen 1989). In High Arctic, where Polar cod is observed in multiyear pack ice it feeds on Amphipoda to a great extent (Lonne and Gulliksen 1989) or on phytoplankton during spring bloom (Andriashev 1954). Wildlife observed in fast ice of West Spitsbergen was typical of such biota but without White whales and Narwhals common at the fast ice edge in the Canadian Arctic (Cross 1982, Bradstreet 1982, Bradstreet and Cross 1982). On the other hand Ringed seals in the inner fjord basins of West Spitsbergen have been observed in abundance and that area is important as a breeding ground (Gjertz and Lydersen 1986, Lydersen and Gjertz 1986, Węsławski and Adamski 1987).

Summarizing the presented information we can state that the fast ice cover of West Spitsbergen fjords develops similarly as in other seasonally changeable areas. Its phyto- and zooplankton assemblages are not abundant and reflect communities typical of the water body of the fjord. The ecological importance of fast ice cover in the investigated area might be expressed as following:

1) fast ice cover form the brackish water layer in early spring, permitting to sustain algae bloom;

2) algae attached to the bottom of the ice floes are drifting during late spring and summer prolonging the vegetation period in ice covered fjords;

3) autumn forming of the fast ice in inner fjords basins create bottom layer of dense and cold water mass, which may act as selective factor for the bethic fauna occurrence;

4) fast ice creates breeding ground for Ringed seals and hence feeding ground for migrating Polar bears.

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Streszczenie

W kilku fiordach Spitsbergenu, w latach 1982–1988, prowadzono badania niektórych właściwości fizyko-chemicznych wody oraz składu fito- i zooplanktonu związanego z lodem. Równolegle dokonywano obserwacji ornitologicznych i badano skład pokarmu dorszyka polarnego (*Boreogadus saida*). Nie stwierdzono obecności typowych, sympagicznych zespołów takich, jakie notowano przy badaniach morskiego paku lodowego. Wyjątkiem były okresy wiosenne lat 1982 i 1988, gdy lód dryfujący z Morza Barentsa współuczestniczył w tworzeniu się zespołów fauny

fiordów. Zooplankton sąsiadujący z lodową pokrywą był ubogi (biomasa poniżej 0.06 g m^{-3}), zaś fitoplankton był typowo jesiennym fitoplanktonem i nie odnotowano specyficznych zespołów podlodowych.

Zawartość chlorofilu a oraz ilość organicznego sedymentu z lodu i z sąsiadującej z nim wody były podobne (0.4 do 1.7 mg m^{-3} chlorofilu oraz 8 do 10 g suchej masy sedymentu na 1 m^2 dziennie).

Skład pokarmowy dorszyka polarnego odpowiadał składowi zooplanktonu, a głównym elementem były widłonogi z rodzaju *Calanus*.

Nie zaobserwowano koncentracji ptaków morskich na pokrywie lodowej fiordów.